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Summary of a Decade of South Ethiopian Coffee Improvement Activities at Awada Coffee Research Center: Fruit of the Landrace Arabica Coffee Variety Development Strategy

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Abstract

Previously the coffee improvement strategy of Ethiopia was aimed to develop widely adaptable and stable cultivars across all coffee growing regions of the country although there is a significant ecological variation that prevails between the major coffee growing regions. Assessing the feedback from users on the performance of released coffee cultivars, the national coffee research program realized the need to initiate coffee improvement programs for each coffee growing region that possessed specific coffee quality and fetch premium price in the world market. In effect, coffee improvement program was initiated for Awada Agricultural Research Center mandated to improve south Ethiopian coffee with the financial aid of the Government of Switzerland. To date about 580 arabica coffee accessions have been collected and maintained in the center in separate sets of collection, and are under evaluation. Forty two (set I) and 16 (set II) selections are under variety trials, 12 selections are in variety verification trial, five hybrids are under variety verification trial and four high yielding cultivars that possessed the typical quality of Yirgacheffe or Sidama coffee types were released to coffee growers in the region. In this paper, coffee improvement activities, such as collection and evaluation of germplasm, variety development activities and genetic studies are reviewed.

Keywords: hybrid coffee cultivars, coffee germplasm accessions, genetic diversity analysis, coffee cultivars, Hararghe coffee

1. Introduction

For more than 2 decades, Ethiopian coffee breeding program was aimed to search for improved coffee cultivars with wider adaptation to biotic and abiotic stresses and maintain stable yield across all coffee growing regions by concentrating the breeding program and source of germplasm only in the southwestern part of the country. However, this research direction has failed especially in providing cultivars that are suitable for the coffee growing areas of the Southern and eastern part of

Ethiopia due to problem of adaptation of the released coffee berry disease (CBD) resistant cultivars in these areas. In addition, these areas possess unique quality coffee types that are inherent only in the local varieties and land races of the respective locations. Hence, the national coffee research program initiated the Landrace Arabica Coffee Variety Development Strategy to establish coffee improvement programs for each coffee growing region that possesses specific coffee quality and fetch premium price in the world market [1]. To improve the yield as well as quality of south Ethiopian coffee, collection of germplasm accessions from the representative areas was undertaken. Consequently, screening of the germplasm accessions for economically important characters commenced and some promising cultivars were identified.

Coffee is the most important export crop of the south Ethiopian region with more than 46% share of the national market. It covers more than 185,000 ha of land in 50 Woredas (districts) among which 11 are high, 7 medium and 32 are low coffee producers. Garden coffee comprises 130,000 ha, semi forest 45,000 ha and forest coffee 10,000 ha. The semi forest and forest coffee production systems are pertinent to the western part of the region. In 2005 cropping season, the annual coffee production of the region was 131,000 tons out of which 100,302 tons were exported as 60% washed and 40% dry processed (SNNPR BOA and NRD, 2008; unpublished). The average yield of coffee in the region is 500 kg/ha (for local or landrace cultivars) while that of the released coffee berry disease resistant cultivars is 800 kg/ha. Though the region is highly endowed with suitable environments, the productivity of coffee per unit area remains very low as compared to the world average. In Southeast Ethiopia (East and West Hararghe zones) coffee was observed to grow as early as 850 AD. In this area coffee is grown in homesteads under intensive management systems with an estimated average holding of less than 0.2 ha of land per family. Planting spaces are very wide and the inter-row spaces are used for intercropping of various types of crops. The major coffee growing districts of Hararghe zones such as Habro, Chercher, Wobera, Garamuleta, Harar Zuria, and Gursum are known for production of best quality coffee [2–5]. On the other hand, yield is reported to be generally low in this region due mainly to the low intensity and erratic rainfall distribution pattern, and also disease problems. The low average yield of coffee in both locations was mainly attributed due to the lack of improved cultivars, shortage of improved agronomic technologies and prevalence of diseases mainly Coffee berry disease and coffee wilt disease. Moreover, physiological problems such as die back due to absence of shade trees coupled with minimum use or absence of agricultural inputs in the smallholder coffee orchards.

Awada Agricultural Research Sub-center is situated in the Tepid to cool semi-arid mid-highland agro-ecology. It is located at about 315 km south of Addis Ababa at 6°3' N of latitude and 38° E of longitude at an altitude of about 1740 m a.s.l nearby Yirgalem town. The area has a semi-bimodal rainfall distribution characterized by double wet and dry seasons with an average precipitation of 1342 mm per annum (1988–1998) and recent data showed 1235 mm per annum (<https://en.climate-data.org/africa/ethiopia/southern-nations/yirgalem-21940/>). The belg (fall) starts in mid-February and extends up to mid-May (i.e., the wet season is from March to May) and the kiremt (winter = main rainy season) extends from June to September/October (i.e., the wet season is from September to October).

The sub-center is mandated to run research activities on Southern Ethiopia coffee types in general and Sidama and Gedeo coffees in particular. Therefore, major emphasis has been given to the development and release of high yielding and disease resistant coffee cultivars that maintain the standard and/or known quality of these coffee types. Four improved cultivars (Angefafa, Koti, Fayate and Odicha) were released to growers and 12 promising selections are in verification trial. To date

more than 580 coffee accessions have been collected and conserved at the center and most have been characterized using the IPGRI [6] coffee descriptor.

2. Arabica coffee improvement activities at Awada Research Center

2.1 Collection, characterization, and evaluation of south Ethiopian coffee germplasm accessions

This trial was laid down on-station at Awada comprising a total number of 538 accessions. The 1994, 1995 and previous Sidama coffee collections (batch I, 206 accessions and 5 checks), that are currently being evaluated for various desirable traits (cherry yield, resistance to CBD, CWD and CLR, and quality parameters) were planted in an augmented design of four blocks and 10 trees per plot (2 m × 2 m spacing between plants, hence each plot had 36 m²) in 1997. The 1996 collections (batch II, 56 accessions and five checks) field established in 1998 was laid down in the same pattern as indicated above. The 1997 collections (batch III), which comprise 55 accessions and three checks, were planted in 1998 in RCB design of three replications and six trees per plot.

Recently new collections were added from four districts of Sidama Administrative Zone. Hundred and twenty coffee accessions collected from Dale and Aleta Wondo districts in 2005 were transplanted in the field at Awada in July 2006 in augmented design. Similarly, 100 coffee accessions collected from Bensa and Dara districts in 2006 were transplanted in the field at Awada in July 2007. Currently the seedlings are at their required stage of growth. Batch I and II were managed in multiple stems as they were stumped due to the severe drought that occurred in 2000. Hence, yield data for 2000, 2001 and 2002 could not be obtained for these two batches.

The first batch composed of 1994, 1995 and previous collection had 4 years yield data (yield data for 2000, 2001 and 2002 not available because the trees were rejuvenated to recover the damage caused by the drought occurred in 2000 main season), the 1996 collection had 5 years yield data and the 1997 collection had 7 years yield data. In the first batch of collections, average of 4 years yield data showed the top six high yielders were well above the best standard check (744) whereas, the top 10 accessions performed better than the other four checks ranging from 17.29 to 26.30 q/ha of clean coffee (**Table 1**). Similarly in the 2nd batch of collections, the top three high yielders were well above the best standard check (744) whereas, the top 10 accessions performed better than the other four checks (**Table 2**). The combined yield data showed that all the top 10 high yielders performed better than the standard checks in the 3rd batch of collections (**Table 3**). Most were free from coffee berry disease and coffee leaf rust under visual assessment score (scored from 0 to 100%; where zero is very resistant and 100% is completely susceptible); however, few accessions scored 3 to 8% infection level under field condition. The top six accessions from batch III were under variety verification trial and another 16 (those ranked from 7 to 22 based on mean yield data) were under variety trial to be evaluated in contrasting environments. Additional 15–20 promising accessions selected from the 1st and 2nd batches of collections were promoted to variety trial in 2009.

2.2 Variety and verification trials of south Ethiopian coffee selections

Three independent experiments were undergoing under this title. The first variety trial was established in two locations; Awada (mid altitude = 1745 m) and Wonago (high altitude = 1850 m), respectively, in 1997 and 1999. This trial consists

Sr. No.	Coll. No.	Clean coffee yield in Qh ^{−1a}					% CBD (visual)		
		1999	2003	2004	2005	Mean	2003	2004	Mean
1	85172	31.14 (28.28)	26.91 (31.07)	22.16 (15.69)	23.87 (25.50)	26.02 (25.14)	0.00	9.31	4.66
2	3883	22.21 (22.13)	12.92 (8.04)	39.55 (41.49)	9.71 (−1.84)	21.10 (17.45)	0.01	6.44	3.23
3	4083	19.79 (16.93)	19.91 (24.07)	24.91 (18.43)	16.35 (17.98)	20.24 (19.35)	0.00	0.03	0.02
4	39772	9.65 (9.57)	22.89 (18.01)	21.40 (23.34)	24.32 (12.77)	19.57 (15.92)	0.01	0.01	0.01
5	695	17.43 (19.11)	22.69 (24.25)	21.06 (20.90)	15.33 (19.67)	19.13 (20.98)	0.00	0.00	0.00
6	85171	20.89 (18.03)	19.23 (23.39)	25.97 (19.49)	6.07 (7.70)	18.04 (17.16)	2.14	10.72	6.43
7	85,170	23.84 (20.98)	12.27 (16.43)	23.78 (17.30)	11.58 (13.21)	17.87 (16.98)	0.00	0.06	0.03
8	2783	13.97 (13.89)	13.88 (9.00)	38.42 (40.36)	3.89 (−7.66)	17.54 (13.90)	0.71	2.15	1.43
9	85298	13.22 (10.36)	10.00 (14.16)	40.91 (34.43)	5.37 (7.00)	17.38 (16.49)	0.00	0.02	0.01
10	2170	14.01 (13.93)	15.49 (10.61)	29.34 (31.28)	10.60 (−0.95)	17.36 (13.72)	0.01	0.31	0.16
LSD at									
0.05		12.66	13.70	17.78	20.50				
0.01		17.75	19.21	24.93	28.75				
Standard checks									
1	74140	10.94	21.60	12.26	7.28	13.02	0.01	0.003	0.0065
2	7487	11.01	16.61	19.71	1.47	12.20	0.07	0.018	0.044
3	7440	13.09	18.96	13.61	3.94	12.40	0.03	0.007	0.0185
4	75227	9.82	21.56	20.31	7.76	14.86	0.02	0.005	0.0125
5	744	16.92	26.84	9.56	18.62	17.99	0.04	0.011	0.0255
F test		NS	NS	NS	NS				
Cv (%)		39.74	25.18	45.73	101.8				
<i>^aFigures in parenthesis are adjusted values. LSD values are used for comparison between un-replicated treatments and replicated treatments. Yield data for years 2000, 2001 and 2002 not available because the coffee trees were severely attacked by drought and thrips as a result they were deformed. Rejuvenation (stumping) was performed in year 2000 that caused 3 years delay in cherry yield.</i>									

Table 1.
Mean yield and reaction to disease of the top 10 high yielding accessions for batch I.

of 42 Arabica coffee selections collected from South Ethiopia in 1970, 1977, 1981 and 1985 and two standard cultivars used as checks. Among the 42 accessions evaluated in the study, mean yield of the top 10 accessions and the standard checks over 4 years are summarized in **Tables 4** and **5**.

At Awada, combined analysis over 4 years showed that none of the top 10 accessions did better than the best check (75227) included in the study though mean yield of the top two selections 1377 and 2081 were not significantly different ($P < 0.05$) from 75227. However, the top nine accessions performed better than the other check (744). Similarly, at Wonago, combined analysis over 5 years indicated

Sr. No.	Coll. No.	Clean coffee yield in Qh ^{-1a}				% CBD (visual)
		2003	2004	2005	Mean	2004
1	96/34	23.81 (23.92)	22.03 (23.95)	28.90 (24.31)	18.68 (18.04)	0.01
2	96/33	20.64 (22.26)	38.20 (36.16)	12.94 (16.25)	17.94 (18.67)	0.01
3	96/1	32.51 (32.62)	17.62 (19.54)	19.15 (14.56)	17.32 (16.68)	3.77
4	96/23	30.11 (31.73)	13.31 (11.27)	23.62 (26.93)	16.76 (17.48)	2.03
5	96/58	32.38 (29.83)	8.97 (10.74)	21.24 (21.13)	15.65 (15.43)	0.00
6	96/11	19.51 (19.62)	22.72 (24.64)	19.78 (15.19)	15.50 (14.86)	0.00
7	96/22	22.48 (24.10)	21.29 (19.26)	16. 81 (20.12)	15.15 (15.87)	0.00
8	96/21	16.35 (17.97)	32.64 (30.60)	11.53 (14.84)	15.13 (15.85)	0.00
9	96/50	10.84 (12.46)	30.04 (28.01)	19.34 (22.65)	15.06 (15.78)	0.00
10	96/41	18.20 (19.02)	27.34 (25.68)	13.01 (14.40)	14.64 (14.77)	0.02
LSD at						
0.05		6.84	14.14	10.52		
0.01		9.59	19.83	14.76		
Standard checks						
1	74140	13.37	10.22	18.62	14.07	0.006
2	7487	15.29	16.59	12.77	14.88	0.003
3	7440	14.85	12.64	12.14	13.21	0.003
4	75227	9.88	6.35	6.11	7.48	0.000
5	744	19.58	17.72	13.85	17.05	0.000
F test		HS	NS	HS		
LSD at						
0.05		6.85		6.29		
0.01		8.97		8.81		
Cv (%)		18.2	43.14	32.13		

^aFigures in parenthesis are adjusted values.
NS and HS are nonsignificant and highly significant respectively at P = 0.05 and 0.01. LSD values are used for comparison between un-replicated treatments and replicated treatments. %CBD = percent coffee berry disease infection level.

Table 2.
Mean yield and reaction to disease of the top 10 high yielding accessions for batch II.

that none of the accessions out yielded the best check (744) though mean yield of the top two selections 1377 and 2081 were not significantly different ($P < 0.05$) from it. Nonetheless, all the top 10 accessions did better than the other standard check (75227) though only the four of the top 10 selections significantly better than 75227. Except for two selections that showed wide adaptability both in terms of yield and resistance to CBD, the rest of the accessions performed differently confirming the fact that Ethiopian coffee landraces generally show specific location adaptation [7].

The second trial, i.e., verification of Sidama coffee selections comprising 14 accessions including two standard cultivars, was established only at two locations in a RCB design of three replications, spacing of 1.5 m × 2 m and plot size of 75 and 66 trees at Konga and Korkie demonstration sites, respectively in 2004. The first cherry yield was harvested in 2007 (**Table 6**). Out of the 12 Sidama coffee selections evaluated in both locations, all the selections except one excelled the two

Sr. No.	Collection No.	Clean coffee yield in Qh ⁻¹						CBD (%)				CLR (%)		
		2001	2002	2003	2004	2005	Mean	ABT		Visual		Visual		
								2003	2004	2003	2004	2001	2003	2004
1	974	9.34	18.49	24.67	40.20	11.02	20.74	0.72	3.76	0.13	0.01	3.89	17.99	4.78
2	9722	14.14	7.96	41.19	10.79	28.84	20.59	0.00	46.80	0.01	0.01	10.68	49.01	9.06
3	979	8.66	14.24	28.18	18.56	28.02	19.53	1.33	37.40	0.02	0.00	1.14	14.44	4.51
4	9718	13.02	12.08	25.41	20.36	23.41	18.86	0.00	54.20	2.23	0.00	14.11	35.77	8.17
5	971	13.32	7.93	25.46	27.34	19.56	18.72	0.00	7.09	0.01	0.01	15.44	48.89	22.39
6	9737	9.49	13.71	21.63	25.01	23.51	18.67	1.42	10.94	0.01	0.00	1.16	30.06	2.00
7	9738	5.84	10.31	23.34	32.12	17.89	17.90	3.04	12.55	0.02	0.01	1.02	16.43	12.00
8	9745	13.21	10.23	27.12	15.81	21.82	17.64	5.80	18.48	0.48	0.00	5.11	36.11	3.11
9	9714	14.39	5.10	33.62	11.37	22.77	17.45	2.67	28.10	0.02	0.00	4.67	37.17	2.68
10	975	10.31	11.83	26.52	17.16	20.35	17.24	4.18	5.60	0.04	0.00	1.02	14.66	4.78
Standard checks														
1	744	5.18	5.03	20.55	23.50	31.09	17.07	1.23	6.99	0.01	0.00	0.92	13.14	1.85
2	75227	4.68	6.12	20.60	18.13	27.71	15.45	0.00	10.33	0.05	0.00	0.12	2.97	1.04
F test		HS	HS	HS	HS	HS	HS							
LSD at														
0.05		4.85	6.75	10.02	11.04	10.61	3.98							
0.01		6.41	8.93	13.25	14.59	14.03	5.24							
Cv (%)		30.89	49.88	29.57	43.38	40.28	39.11							
HS, highly significant at P = 0.01; ABT, attached berry test, test for coffee berry disease by artificial inoculation while the young berries are still attached on the tree; CBD, coffee berry disease; CLR, coffee leaf rust.														

Table 3
Mean yield and reaction to diseases of the top 10 high yielding accessions for batch III.

Sr. No.	Accessions	Clean coffee in Qh ⁻¹					CBD visual (%)			CLR visual ^a
		1999	2003	2004	2005	Combined mean (03–05)	2000	2004	Mean	2003
1	1377	19.34	21.45	22.59	23.19	22.41	1.49	0.003	0.747	9.2
2	2081	21.35	16.06	38.39	12.18	22.21	4.87	0.638	2.754	4.75
3	85188	19.29	24.36	27.24	13.26	21.62	8.93	0.381	4.653	19.85
4	3677	15.91	26.68	19.24	18.39	21.43	8.04	0.628	4.332	26.85
5	2970	12.19	23.53	25.42	14.98	21.31	10.16	0.003	5.081	13.4
6	85245	10.48	22.76	20.65	19.81	21.07	7.03	0.005	3.518	3.61
7	85180	17.90	23.43	18.15	20.31	20.63	0.48	0.000	0.238	10.3
8	2181	17.48	21.44	23.01	16.84	20.43	13.85	0.388	7.120	17.65
9	3070	12.62	28.59	21.33	10.19	20.03	33.26	2.625	17.94	14.35
10	85257	16.39	22.35	15.01	20.34	19.23	0.38	0.006	0.191	22.35
Standard checks										
1	75227	6.73	24.28	26.75	26.00	25.68	0.18	0.009	0.09	0.39 (3.49)
2	744	12.67	19.18	10.25	31.61	20.35	0.24	0.003	0.12	5.11 (12.22)
F test		HS	HS	HS	HS	HS				
LSD at										
0.05		4.64	4.61	7.70	6.12	3.59				
0.01		6.13	6.09	10.16	8.08	4.73				
Cv (%)		24.22	19.28	31.71	34.33	28.49				

^aFigures in parenthesis are transformed value.
HS, highly significant at P = 0.01; CBD, coffee berry disease; CLR, coffee leaf rust.

Table 4.
Mean yield and reaction to diseases of the top 10 high yielding accessions at Awada.

standard checks in 2007 cropping season. However, relatively higher yield was recorded for all the selections in Konga as compared to Korkie; and coffee berry disease infestation was relatively higher for Konga than Korkie.

The third trial was proposed to be undertaken in two sets; consequently, seedlings of 16 selections and two standard checks were transplanted at three sites (Awada, Wonago and Kumato) in August 2006. Set II was established in 2009. The seedlings were well established in the fields of the three locations.

2.3 Coffee hybrid variety development activity

Several reports have described heterosis in *Coffea arabica* with average up to 30% hybrid F₁ cultivars [8–12]. In an effort to develop high yielding, CBD resistant coffee hybrids that possess the standard quality of Sidama and Gedeo coffee in the mid and high altitudes of the south, a hybridization experiment was initiated in 1996. Through series of observations made since 1998 for yield, CBD resistance and quality of the crosses, it was possible to identify more than eight hybrids superior over the standard checks for the traits considered. Moreover, a maximum over parent heterosis of 44.6% for yield was obtained (4 years average data) for the 15 hybrids studied (Tables 7 and 8). Of these 15 hybrids, 8 of them exhibited average

Sr. No.	Collection No.	Clean coffee yield in Qh ⁻¹						CBD (%)			CLR visual (%) ^a
		2001	2002	2003	2004	2005	Combined mean	ABT	Visual		
								2004	2003	2004	
1	85259	5.36	9.98	28.29	11.11	20.98	15.14	14.07	5.07	3.56	1.39
2	85238	8.55	9.53	23.40	10.20	15.39	13.41	57.83	0.073	0.64	3.26
3	3670	6.80	10.54	24.94	12.27	11.69	13.25	40.34	3.87	3.89	4.00
4	85294	6.53	9.69	25.87	11.98	10.98	13.01	68.19	1.45	1.09	9.66
5	85232	6.50	5.05	20.42	12.69	14.38	11.81	37.73	9.20	8.89	1.86
6	1870	4.98	4.54	23.22	10.63	15.33	11.74	49.94	2.38	1.63	14.55
7	1377	6.21	7.21	18.84	12.62	12.46	11.47	31.03	0.11	2.39	2.27
8	85257	6.11	6.07	25.47	7.93	10.24	11.16	9.50	0.47	0.26	4.20
9	2077	7.17	5.96	21.27	11.95	9.30	11.13	41.02	9.91	12.76	8.15
10	85296	7.15	7.84	21.86	7.85	10.64	11.07	48.08	28.18	7.17	9.08
Standard checks											
1	744	6.24	11.09	28.82	10.34	20.64	15.43	12.30	0.12	0.01	0.81
2	75227	4.70	7.78	16.90	10.13	14.95	10.89	3.54	0.01	0.30	0.48
F test		HS	HS	HS	HS	HS	HS				
LSD at											
0.05		3.36	3.20	6.22	4.68	5.54	2.10				
0.01		4.45	3.99	8.22	6.18	7.32	2.76				
Cv (%)		45.39	41.55	27.67	38.91	40.19	37.53				
<i>^aFigures in parenthesis are transformed values.</i>											
<i>HS, highly significant at P = 0.01; CBD, coffee berry disease; CLR, coffee leaf rust; ABT, attached berry test.</i>											

Table 5.
Mean yield and reaction to diseases of the top 10 high yielding accessions at Wonago.

yield of above 15 qts/ha of clean coffee, which is well above the performance of the standard checks included in the experiment [13]. Among these eight hybrids, five (744 × 1377; 7440 × 2077; 75227 × 1377; 75227 × 2077; 75227 × 1681) were proposed to be promoted to verification trial to confirm the repeatability of their performance across locations and years since consistency of repeatability of technology performance between research stations and farmers’ fields may not hold universally the same, as there is high variability among farm conditions and response to improved crop management is less favorable in farmers’ fields due to many conditions [14]. Variety verification experiments are designed to compare the superiority of new cultivars identified as promising by variety trials over that of the farmers’ existing practices. Ethiopian indigenous arabica coffee cultivars are location specific in terms of good performance [15]. In the case of Southeastern Ethiopia coffee improvement program, hybrids are currently being evaluated for yield, resistance to major coffee diseases and quality parameters. Based on the 4 years data both high yielders and disease resistant hybrids were identified [16]. Evidence showed that there is a wide variation in environmental conditions within the southern coffee growing areas (Sidama and Gedeo Zones) that important G × E interaction might occur [16]. Therefore, the adaptability of these hybrids should be tested across locations with larger plots to verify their response to yield, major coffee diseases and other important characters.

Sr. No.	Selections	Clean coffee yield in q/ha	
		Korkie	Konga
1	85238	2.29	4.85
2	9718	4.45	4.93
3	85237	3.45	4.63
4	974	3.63	5.68
5	1377	5.22	5.75
6	9744	4.17	5.56
7	744*	1.28	4.33
8	979	3.18	8.35
9	9722	2.07	6.97
10	85294	5.61	5.04
11	85259	1.21	2.15
12	85257*	2.28	4.99
13	971	3.41	8.43
14	75227	1.30	2.58

*Selections 744 and 75227 were standard checks (released CBD resistant cultivars).

Table 6.
Mean yield and reaction to diseases of the two selections and two standard checks.

3. The released south Ethiopian coffee cultivars

3.1 Angefa (breeder’s reference: selection 1377)

Awada Agricultural Research Center (AARC) has released an improved cultivar named “Angefa” in 2006; which was high yielder and well adapted to Sidama and Gedeo coffee growing areas. This cultivar was originated from this region and represents the local coffee types plus positive advantages, i.e., resistant to coffee berry disease, high coffee bean yield (24 qt/ha on research station of Awada) and also superior qualities [17].

In relation to the previously released coffee berry disease resistant cultivars originated southwest of Ethiopia, Angefa is highly preferred by coffee farmers of Sidama and Gedeo Zones for its high vigor, yield advantage and quality characters and it fits in well with the government’s strategy of strengthening the development of local landrace coffee varieties. Currently Awada Agricultural Research Center is the only source of seed for this cultivar and the demand for this cultivar in the country is very high. Angefa was initially collected from Quoti Kebele of Wonago district in Gedeo Zone of south Ethiopian region. It can be described as follows; it has an open type of growth habit, bronze leaf tip color, can grow at an altitude range of 1700–2000 m. The rainfall requirement of this cultivar is well above 1200 mm per annum. It grows best in Nitosol type of soil with the application of 125 kg DAP and 81 kg of Urea fertilizers per hectare. It can give 11 to 17 quintals of clean coffee per hectare on farmers’ field. It requires 50% shade using common shade trees like *Milletia*, *Cordia*, *Albizia*, *Sesbania* and *Acacia* species. A spacing of 2 m × 2 m is the best recommended practice as the cultivar has open type of growth habit. In reaction to major coffee diseases, it is resistant to CBD and moderately

Sr. No.	Hybrids	Clean coffee yield in Qh ^{-1a}					
		2003	2004	2005	Combined mean	% Heterosis	
						OMP	OBP
1	744 × 1681	34.78	39.44	31.04	35.08	59.85	50.17
2	1377 × 1681	29.41	45.15	20.41	31.66	36.17	35.53
3	75227 × 1681	24.77	48.08	18.19	30.34	62.12	29.88
4	744 × 2077	29.74	18.58	40.55	29.63	52.54	44.32
5	7440 × 75227	35.85	11.12	40.89	29.29	89.09	81.73
6	7440 × 1681	27.82	32.84	25.07	28.57	41.89	22.3
7	7440 × 1377	30.01	17.34	37.71	28.35	41.57	22.35
8	75227 × 1377	27.61	24.04	32.94	28.20	51.57	21.87
9	7440 × 2077	26.18	25.98	32.15	28.11	59.58	53.44
10	744 × 1377	29.75	16.81	35.58	27.38	25.40	18.32
11	75227 × 2077	22.61	34.05	23.78	26.82	65.61	46.4
12	2077 × 1681	20.66	40.85	14.69	25.40	21.88	8.73
13.	1377 × 2077	23.41	21.31	28.93	24.55	18.43	6.09
14.	744 × 7440	26.70	9.12	36.73	24.18	29.17	17.78
15	744 × 75227	25.00	14.65	26.02	21.89	26.53	6.62
Parents							
16	744	18.71	12.68	30.21	20.53		
17	7440	19.19	9.03	22.51	16.91		
18	75227	10.45	18.50	13.26	14.07		
19	1377	22.89	18.71	27.81	23.14		
20	2077	13.36	23.07	18.54	18.32		
21	1681	20.19	36.03	13.86	23.36		
F test		HS	HS	HS	HS		
LSD at							
0.05		7.77	10.19	12.47	5.85		
0.01		10.33	13.55	16.60	7.72		
CV (%)		22.2	29.25	32.01	28.45		
HS, highly significant at P = 0.01; OMP, heterosis over mid-parent; OBP, heterosis over better parent.							

Table 7.
Mean yield of hybrids between south Ethiopian and southwest Ethiopian coffee genotypes at Awada.

resistant to CLR under field conditions both at Yirgalem and Wonago areas. It is also characterized by Yirga Chefe type of cup test with best raw and roast quality.

3.2 Odicha (breeder’s reference: selection 974)

Odicha was released in 2010 by AARC for mid altitude (1740–1850 m) coffee growing areas of Sidama and Gedeo zones of Southern Nations and Nationalities and Peoples Region (SNNPR). It is characterized by high cherry yield potential (above the checks) and moderately resistant to coffee berry disease and highly resistant to coffee leaf rust under field conditions. It is also moderately and highly

Sr. No.	Hybrids	Clean coffee yield in Qh ⁻¹							CBD visual (%)		CLR visual ^a (%)	
		2000	2001	2002	2003	2004	2005	Combined mean	Heterosis (%)		2003	2003
									OMP	OBP		
1	75227 × 1377	4.76	15.28	21.63	28.82	20.79	34.81	21.02	65.38	51.77	3.81	3.81 (10.75)
2	75227 × 1681	5.65	12.47	23.45	28.54	27.74	26.46	20.72	99.81	79.08	2.21	2.21 (8.38)
3	7440 × 2077	7.52	8.32	28.21	16.78	36.61	19.27	19.45	163.91	48.13	2.52	2.52 (8.38)
4	744 × 1681	4.53	8.48	23.52	24.53	26.74	24.16	18.66	69.25	44.88	0.23	0.225 (2.5)
5	75227 × 2077	5.26	12.15	23.85	20.60	25.21	24.81	18.64	182.85	61.11	0.16	0.16 (1.11)
6	744 × 2077	6.08	11.60	24.49	15.80	27.21	25.98	18.53	155.76	43.87	1.10	1.21 (5.93)
7	7440 × 75227	6.59	8.66	26.85	22.58	22.09	21.44	18.03	45.99	37.32	0.96	0.96 (5.38)
8	744 × 1377	5.03	8.48	19.37	23.69	21.81	26.97	17.56	31.39	26.79	0.46	0.46 (3.01)
9	7440 × 1681	1.05	11.81	20.92	25.69	23.93	20.04	17.24	54.62	31.30	1.13	1.13 (4.66)
10	744 × 75227	4.68	9.11	21.08	18.43	22.94	24.56	16.80	37.42	30.43	1.71	1.71 (7.32)
11	7440 × 1377	0.85	9.02	17.77	20.36	20.55	26.47	15.84	17.42	14.37	2.13	2.13 (8.29)
12	1377 × 2077	3.64	10.18	20.42	14.69	26.39	18.29	15.60	101.81	12.64	0.34	0.335 (2.99)
13	744 × 7440	2.75	6.9	16.74	16.55	20.01	22.90	14.31	165.49	8.99	1.15	1.15 (5.54)
14	2077 × 1681	3.14	5.76	10.34	20.71	19.73	19.27	13.16	1.19	43.51	1.46	1.46 (6.75)
15	1377 × 1681	0.21	5.55	14.50	16.18	21.76	18.85	12.84	11.56	-7.29	0.86	0.86 (4.51)
Parents												
16	744	3.10	5.73	12.46	19.66	15.52	20.83	12.88			0.40	0.4 (3.58)
17	7440	3.82	8.65	17.84	14.20	19.27	15.05	13.13			1.06	1.06 (5.42)
18	75227	2.20	7.58	14.19	15.02	11.74	18.70	11.57			0.51	0.51 (3.44)
19	1377	3.34	8.44	14.26	21.13	14.67	21.24	13.85			1.72	4.72 (11.73)

Sr. No.	Hybrids	Clean coffee yield in Qh ⁻¹							CBD visual (%)		CLR visual ^a (%)	
		2000	2001	2002	2003	2004	2005	Combined mean	Heterosis (%)		2003	2003
									OMP	OBP		
20	2077	0.21	0.11	0.55	2.79	4.11	1.89	1.61			12.50	12.5 (20.7)
21	1681	2.54	5.99	6.70	11.67	16.15	12.00	9.17			0.66	0.66 (3.45)
F test		HS	HS	HS	HS	HS	HS	HS				
LSD at												
0.05		2.93	4.55	7.32	8.68	9.25	10.26	3.06				
0.01		3.90	6.05	9.74	11.54	12.30	13.64	4.03				
CV (%)		56.57	37.19	28.67	32.33	30.87	34.3	35.31				

Table 8.
Mean yield and reaction to diseases of crosses in set B at Wonago.

resistant to CBD and coffee wilt disease (CWD) in seedling inoculation test under controlled evaluation facility, respectively. Odicha is well adapted to the region even in marginal areas like Korke and has vigorous growth (with strong and tough stem and branches) and highly acceptable cup quality. It is medium open in growth habit which has very attractive appearance with manageable height and canopy diameter. This cultivar has an open type of growth habit with strong and stiff stem. The branches are very dense and uniformly distributed on the tree and are horizontally spreading. The leaves are long and medium wide. Both matured and young (leaf tips) leaves are green in color. Matured and ripe cherries are medium round sized and red in color.

Odicha represents both the typical quality profiles of Sidama and Yirgacheffe coffee types which are spicy at Awada and floral at Konga. Besides its representation of quality profile of the locality, the cultivar has good and acceptable raw and cup quality profile under appropriate and recommended processing method. Generally, it has comparable overall quality standard with the checks and typical flavor profile representation than the standard checks.

Biennial bearing habit is the inherent characteristics of arabica coffee, which predominantly contributes to irregularity of bearing from year to year. Cultivar Odicha has revealed regular bearing habit within the acceptable range.

3.3 Fayate (breeder's reference: selection 971)

Fayate was also released in 2010 by AARC for mid altitude (1740–1850 m) coffee growing areas of Sidama and Gedeo zones of SNNPR. Fayate is highly resistant to CBD and better performed in highland areas like Wonago and Konga (Yirgacheffe). In addition, selection 971 is resistant to CWD under greenhouse conditions; hence this selection can be preferably promoted to areas where CWD infestation is severe.

Fayate is characterized by high potential for cherry yield (above the checks) with highly consistent bearing habit that is unlike to most cultivars of arabica coffee. It is resistant to coffee berry disease both at visual and attached berry test evaluations. It is well adapted to the region and with highly vigorous plant that possesses strong stem, wider canopy, and strong and very long branches. It is characterized by open type of growth habit with strong and stiff stem. The branches are open and uniform across the tree. The type of branching habit is horizontal and spreading. Matured leaves are narrow, short in size and green in color. The leaf tips (shoot tips) are also green colored. It has round and medium sized cherries that become red when ripe.

Fayate represents the typical quality profile of Sidama coffee types which is characteristically known as spicy. It has good and acceptable raw and cup quality profile under appropriate and recommended processing method. The cultivar produces very acceptable export standard bean size grading. Generally, Fayate has comparable overall quality standard with the checks and typical flavor profile representation than the standard checks (744 and 75227). Fayate expressed a fairly regular bearing habit as evidenced by value of 36 over 7 years yield data at AARC, while the standard checks 75227 and 744 showed 72.17 and 63.70 at this location, respectively.

3.4 Koti (breeder's reference: selection 85257)

Cultivar Koti was also released in 2010 by AARC for mid altitude (1740–1850 m) coffee growing areas of Sidama and Gedeo zones of SNNPR. Like Fayate, Koti is also highly resistant to CBD and better performed in highland areas like Wonago and

Konga (Yirgachefe). Koti is characterized by an average potential for yield with fairly consistent bearing habit. It is highly resistant to coffee berry disease and well adapted to highland areas where coffee berry disease pressure is high. Its medium vigor (manageable height and medium canopy) can be an advantage for close spaced planting which is preferred by smallholder farmers. It also meets the standard quality (Yirgachefe and/or Sidama type) of cup test which is not achieved by the southwest released CBD resistant cultivars. It is characterized by intermediate growth habit and light bronze leaf tip color. This candidate also showed stability in yield (in contrast to specific adaptation behavior of arabica coffee varieties) as evidenced in the variety trial conducted at Awada (mid altitude) and Wonago (high altitude).

This cultivar can be expressed by thin and flexible stem along with open type of growth habit. Branches are shallowly (openly) distributed uniformly from bottom to top. The orientation of branches is horizontal and spreading. Leaf tips are bronze while matured leaves are dark green in color and broad and long in size. The matured and ripe cherries are red colored, small sized and round shaped. In addition the cherries possess persistent calyx that is a morphological marker for resistance to coffee berry disease.

4. Genetic studies

4.1 Summary of genetic studies

Since Ethiopia is the primary center of origin and genetic diversity for *C. arabica*, there is high genetic variability for yield and yield components, disease and pest resistance, and other traits. Systematic studies conducted on genetic diversity analyses of Ethiopian coffee germplasm using morphological characters confirmed the prevalence of enormous variation for economically important traits. Cluster and principal component analyses conducted on 100 Hararghe coffee germplasm accessions collected from 16 districts of East and West Hararghe Administrative Zones with four standard checks using 14 quantitative characters produced six clusters. The number of accessions per cluster ranged from five in cluster VI to 44 in cluster III. Moreover, the first four principal components explained 78.5% of the total variation prevalent within the germplasm accessions out of which 38.5% was explained by the first principal component. Similarly, a field experiment conducted on evaluation of 41 south Ethiopian coffee accessions with two standard checks of the southwest Ethiopian origin using seven morphological agronomic characters, average of 3 years data on severity of CBD and CLR infestations and clean coffee produced nine clusters. The number of accessions per cluster ranged from one in cluster IX to 13 in cluster II. Further, the first four principal components explained 82.63% of the total variation prevalent within the germplasm accessions out of which 32.52% was explained by the first principal component. The clustering pattern of the accessions revealed the prevalence of genetic diversity in the south and Southeast Ethiopian coffees for the characters considered. The study highlighted the possibility of using accessions of the distant clusters as potential candidates for the genetic improvement of both coffee types through crossing and selection. However, these reports shall be further confirmed through molecular techniques of genetic diversity analysis using the same material or germplasm.

4.2 Introduction to genetic studies

For any crop improvement program, a breeder depends on the variability present in the germplasm collections in order to advance in production, bring about

stability to different biotic and abiotic stresses or effect changes in crop characteristics, and meet breeding interest [18]. In cognizant of this fact and in order to alleviate the stated production problems, a concerted efforts of coffee germplasm collection were undertaken for 3 years (1995–1997) from different coffee growing areas of Central and Southeastern part of the south Ethiopian region which resulted in the maintenance and evaluation of more than 350 coffee germplasm accessions at Awada research sub-center. Moreover, in 1998 coffee germplasm collections were conducted from different coffee growing areas of Hararghe by JARC and as a result more than 900 accessions were collected and maintained at the center.

Several workers have estimated the extent of genetic diversity present from the different sources of arabica coffee germplasm collections. For instance, a study by [19] on second progeny arabica coffee collections of Ethiopian origin indicated the prevalence of high level of variability in morphological, agronomic and biochemical characteristics. The genetic diversity analysis conducted by [20] by employing RAPD markers on cultivated and sub-spontaneous accessions of arabica coffee confirmed the narrow genetic base of commercial cultivars (3 typica and 3 bourbon types). On the other hand, they reported the existence of large genetic diversity within the sub-spontaneous material, which consisted of 11 samples representing the different coffee growing areas in Ethiopia. Further, they have suggested the prevalence of an east–west differentiation in the Ethiopian coffee germplasm. Similarly, Montagnon and Bouharmont [21] characterized 148 arabica coffee accessions for phenotype diversity under field condition. They have evaluated the accessions using 18 different morphological and agronomic traits by employing multivariate analysis and identified two main groups in the coffee accessions. According to them, accessions of group I have a more erect branching habit, narrower leaves, and were more resistant to coffee leaf rust and coffee berry disease than accessions of group II. They further opined that group I mostly contained Ethiopian arabica coffee accessions collected from west of Great Rift Valley, whereas group II contained commonly cultivated varieties throughout the world and Ethiopian accessions collected from east of Great Rift Valley in Ethiopia (south and southeast Ethiopia).

Though the reports of the above workers indicated the prevalence of lower genetic variations in the south and southeast Ethiopian coffee types, there was no systematic study conducted to quantify and verify the level of genetic diversity in both locations using large number of samples. Rather the conclusions were drawn from evaluation of few commercial cultivars originated from southeast Ethiopian coffee growing region alone. Therefore, the objective of this review paper is to report the major findings obtained from the systematic studies conducted on coffee germplasms of both South and Southeast Ethiopian coffee growing regions so that one may readily use it in the ongoing breeding program.

4.3 Research findings

Genetic diversity analysis was conducted at Wonago Agricultural Research Sub-Station on 41 south Ethiopian coffee selections collected from six Woredas of Gedeo, Sidama, and Wolayta zones along with two released coffee berry disease (CBD) resistant cultivars originated from Southwest Ethiopia [22]. Data on seven morphological agronomic characters vis-à-vis stem girth, plant height, number of primary branches, number of stem nodes, length of longest primary branches, canopy diameter and internode length of the main stem; percent disease infestation levels on CBD and coffee leaf rust (CLF) and average of 3 years clean coffee yield was obtained on the 43 genotypes. The ANOVA showed a highly significant difference among the genotypes for the seven morphological agronomic characters and

yield. Southeast Ethiopian coffee population was stated to be of narrow genetic base [20, 23], however, the findings of this study indicates the presence of wide variations among Southeast Ethiopian (Sidama, Gedeo and Wolayta) landrace coffee populations located east of the Great Rift Valley. This might be attributed to the differences in the type of collections used, i.e., forest coffee versus landraces.

The cluster analysis grouped the 41 south Ethiopian coffee selections and the two southwest Ethiopian origin CBD resistant cultivars in to nine clusters suggesting the prevalence of wide phenotypic variations in the coffee populations (**Table 9**). The number of genotypes per cluster varied from one in cluster IX to 13 in cluster II. Cluster III contained selections only from Gedeo Zone (Yirgachefe & Wonago districts). On the same manner, cluster V except one selection from Wonago, was composed of selections obtained from Sidama Zone (Dale and Aleta Wondo districts). The two CBD resistant cultivars (75227 and 744) used as checks were grouped in clusters VI and VII where each cluster had three selections. The selections from Wonago district distributed in to six clusters where seven out of 16 were grouped in cluster II. Similarly the selections from Yirgachefe district distributed in to five clusters where four out of 11 were grouped in cluster III. Relatively low mean yield and higher scores of both CBD and CLR infestations characterized cluster IX that contains only one selection from Yirgachefe district (**Table 9**).

The intra and inter-cluster distance (D^2) analysis showed a highly significant ($P < 0.01$) difference among clusters. The smallest inter-cluster distance (18.6) was observed between clusters VI and VII while the highest (134.7) was between clusters V and VIII. In most of the cases, the genotypes among the clusters were significantly ($P < 0.001$) divergent from each other. Considering the intra-cluster (within cluster) distance, no significant genetic dissimilarity was detected (data not shown).

The first four principal components with eigenvalues greater than unity explained 82.63% of the total variation among the 43 genotypes for the 10 quantitative characters measured. Principal component one accounted nearly one third (32.52%) of the total variation. In light of the results obtained from the PCA, it may be possible to deduce that more than half (53%) of the variation obtained was primarily due to number of nodes, primary branches, and plant height.

Similarly, genetic diversity analysis was conducted at Awada Agricultural Research Sub-Center on 100 coffee accessions collected from 16 districts of East and West Hararghe Administrative Zones along with four released coffee berry disease

Woreda	Clusters									Total selections per Woreda
	I	II	III	IV	V	VI	VII	VIII	IX	
Yirgachefe	—	4	4	1	—	1	—	—	1	11
Wonago	3	7	2	1	1	1	1	—	—	16
Dale	—	—	—	—	2	—	—	—	—	2
Aleta Wondo	1	2	—	—	2	—	1	1	—	7
Sodozuria	—	—	—	1	—	—	—	—	—	1
Bolososore	—	—	—	—	—	—	1	1	—	2
Southwest	—	—	—	—	—	1	—	1	—	2
Unknown	1	—	1	—	—	—	—	—	—	2
Total	5	13	7	3	5	3	3	3	1	43

Source: Mesfin et al. [22].

Table 9.
Distribution of the 43 genotypes over nine clusters based on the 10 characters considered in the study.

(CBD) resistant cultivars originated from Southwest Ethiopia [24]. Data on 14 morphological agronomic characters vis-à-vis plant height, internode length of the stem, internode length of branch, number of internodes of the stem, number of internodes on the longest primary branch, total number of internodes per plant, canopy diameter, stem diameter, leaf area, number of primary branches, angle of primary branches from the main stem, number of secondary branches, length of the longest primary branch and average length of primary branches was obtained on the 104 genotypes. The ANOVA showed a highly significant difference among the genotypes for all the 14 characters considered in the study suggesting the presence of high variability among the accessions. In view of this, it may be reasonable to state that there is a good chance to improve Hararghe coffee accessions through selection and breeding.

The cluster analysis grouped the 104 coffee germplasm accessions into six clusters (**Table 10**). The size of cluster varies from five accessions in cluster V to 44 accessions in cluster III. Clusters I, II, and IV contained accessions mainly from the Western Hararghe districts whereas clusters III and V had almost equal number of accessions from both east as well as West Hararghe districts. The five accessions in cluster VI were from the two districts of West Hararghe out of which four originated from Kuni and only one from Chiro District. Three of the CBD resistant cultivars (75227, 74165 and 74140) used as checks were grouped in cluster I, where middle to high altitude accessions from Western Hararghe districts was most frequent. The fourth check, F-59 was grouped in cluster II, confirming the fact that this cultivar was distinctly different from the rest standard checks in morphology and geographical origin. It was evident that the accessions from Eastern Hararghe districts' showed close similarity (**Table 10**) with regard to their clustering patterns. For instance, the germplasm accessions from Gursum, Bedeno and Dedder Districts were found to be distributed in clusters II and III. On the other hand, accessions from Kombolcha, Girawa and Meta were scattered in clusters I, II and III where majority of their accessions were grouped in cluster III. In general, cluster III represented 58.5% of the germplasm accessions from Eastern Hararghe districts. Similarly, more than 65% of the germplasm accessions from Darolabu, Mesela and Tulo Districts of Western Hararghe were concentrated in cluster III. Accessions from Habro and Boke Districts appeared in the same clusters, i.e., clusters I, II, and III, even though, majority of their accessions appeared in the first two clusters. The germplasm accessions of Girawa, Bedeno, Kuni, Chiro, Mesela and Habro Districts were found distributed their accessions in four different clusters, which suggested that the germplasm accessions from these districts were relatively more variable. In respect to the remaining districts, the accessions were found distributed in two or three clusters, probably reflecting less variation among germplasm accessions within a particular district.

Zone	Cluster						Total accessions
	I	II	III	IV	V	VI	
East Hararge	6	6	24	2	3	—	41
West Hararge	11	13	20	7	3	5	59
South west Ethiopia *	3	1					4
Total	20	20	44	9	6	5	104

**Represented standard checks.*
Note: This table was extracted from the dendrogram. Source: Mesfin and Bayetta [24].

Table 10.
Distribution of the 104 coffee genotypes over six clusters based on quantitative traits.

Based on Mahalanobis's D^2 statistics, highly significant inter-cluster distances were obtained. Cluster II showed the maximum and significant genetic distance (102.12) from cluster VI. Further, the inter-cluster distances between clusters I and V, I and VI, II and IV, II and V, II and VI, III and VI, IV and V, and V and VI in that order were found to be highly significant. The first four principal components explained 78.5% of the total variation. Principal component one accounted more than one third (38.5%) of the variation. In light of the results obtained from principal component analysis, it may be possible to deduce that maximum variation (38.5%) accounted by principal component one was represented by such quantitative characters as length of the longest primary branch, stem diameter, total number of internodes per plant and total number of primary branches per plant.

The cluster analyses conducted for both locations, i.e., South and Southeast Ethiopia failed to clearly show relatedness of the selections due to geographical origin. Rather it is evident that there is overlapping of clustering patterns in respect of all Woredas, which could be explained as lack of differentiation among Woredas arising partly due to gene flow [25]. In light of the results obtained from the principal component analyses, it may be possible to deduce that more than half (53%) of the variation obtained in the south Ethiopian coffee was primarily due to number of stem nodes, primary branches, and plant height. Similarly, length of the longest primary branch, stem diameter, average length of primary branches, total number of internodes per plant and total number of primary branches per plant were the five important characters that contributed most to the total variation in the first principal component. This perhaps emphasized the significance of these characters to the appraisal of genetic diversity in the south and southeast Ethiopian landrace coffee populations in that order.

4.4 Conclusions and recommendations

Overlapping of the clustering patterns of the accessions from different districts of both locations indicated lack of differentiation among districts to a certain extent. Moreover, germplasm accessions from western Hararghe districts were relatively more variable in their clustering patterns as compared to eastern Hararghe districts. Based on this, it can be inferred that western Hararghe could serve as a potential source of variability for Hararghe coffee. Similarly, selections from Gedeo Zone were more divergent than selections of Sidama Zone though relatively greater number of selections was considered from Gedeo Zone. Further, it is also possible to state that quantitative characters studied significantly contributed to the elucidation of genetic diversity prevalent in the region.

The significant inter-cluster distances between clusters indicated that there is a high opportunity for obtaining transgressive segregates and maximize heterosis by crossing germplasm accessions belonging to these clusters. Therefore, the grouping of accessions by multivariate methods could be of considerable practical value to the coffee breeders so that representative accessions could be chosen from such clusters for hybridization programs. Moreover, the quantitative characters vis-à-vis number of stem nodes, primary branches, plant height, length of the longest primary branch and stem diameter could be used as a selection criterion for improving the productivity of the crop since they represent the lion's share in the variability of the coffee population in the specified area.

4.5 Gaps and challenges

The number of germplasm accessions, the locations (number of districts) and the number of characters considered for the south Ethiopian coffee were small,

moreover, the germplasm collections from the Southeast Ethiopia (Hararghe zones) were appraised at pre-bearing stage only. It is however, necessary that the expression of different characters need to be studied with additional accessions over several bearing years. Furthermore, additional traits of interest and molecular techniques may be very useful in order to further confirm the present encouraging result that indicated the presence of considerable variations within South Ethiopia and Hararghe coffee populations that provides immense potential for the development of improved varieties from the local landraces for the area.

4.6 Future directions

The studies brought out that Gedeo Zone and Western Hararghe appeared to be the target areas for future intensive germplasm exploration endeavors of both locations. In the meantime, evaluation of the maintained germplasm collections for yield, quality and disease resistance must continue to provide improved cultivars for coffee growers of both regions in the shortest time possible to minimize the risk of losing smallholder coffee orchards challenged by the severe competition with chat (*Catha edulis*) especially in the Hararghe coffee growing districts.

Genetic diversity analysis using molecular techniques should be conducted on those germplasm accessions so as to confirm the results obtained and avoid duplications of accessions or genotypes. Moreover molecular markers shorten the lengthy conventional breeding scheme through the use of marker-assisted selections.


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